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Integration of Desalination and Renewables, a Demonstration of the Desalination Module in the H2RES Model: Case Study for Jordan

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Water scarcity and the dependence on fossil fuels as a primary source of energy are crucial problems for a number of arid countries. The integration of energy and water systems presents a possible solution for both issues. The flexibility of a desalination system can increase the possibility for the penetration of intermittent renewable energy sources and thus provide both fresh water and the potential for the local production of clean energy.
Jordan is the fourth most water deprived country in the world and is also highly dependent on energy import. Almost all of its primary energy comes from imported fossil fuels, mostly from natural gas. It is a country rich in wind and solar energy but unfortunately, almost no utilization of that potential. The integration of desalination systems and renewable energy sources is a possible solution both for Jordan's water and energy supply.
The goal of this paper is to demonstrate the desalination module in the H2RES model using Jordan as a case study. H2RES is a flexible energy modelling tool used for the balancing of energy supply and demand on an hourly basis. It is capable of demonstrating the benefits of water and energy integration for the purpose of increasing the penetration of intermittent renewables and the reduction of CO_2 emissions. For this purpose, four scenarios have been created. The first one is a business as usual scenario with no desalination, a desalination scenario and two desalination scenarios that utilize the produced brine as energy storage in pump hydro plants. The results will show that the utilization of desalination, especially in the case where desalination is combined with pump storage, can help increase the penetration of renewable energy sources into the electrical grid and thus help decrease the dependence on energy import and reduce the CO_2 emissions of the energy system.

1. Introduction

Water shortage and an underutilized potential for electricity production from renewable energy sources are a common problem in a lot of arid regions around the World. One such region is the country of Jordan. It has a substantial potential for the production of electricity from wind power (Alsaad, 2013) as well as PV (Ashhab et al., 2013) but almost no utilization of said potential. In the year 2010 over 99 % of the produced electricity in Jordan came from natural gas and oil products (IEA, 2013). Jordan is also the World's fourth most water deprived country with an annual water consumption of only 145 m^3/capita (MWI, 2009) which is far below the established water poverty line of 500 m^3/capita annually (UN, 2007). Both of these issues will only get worse in the future if nothing changes since the population of Jordan is predicted to increase by 50 % until the year 2030 (DOS, 2013) and their official energy strategy predicts an annual increase of electricity consumption of 7.4 % annually until the year 2020 (Jordan, 2007).
Both the water and energy supply problems can be addressed with the utilization of renewable energy sources (RES) and desalination. The potential that RES have on the increase of the energy independence

and the reduction of CO_2 emissions of an energy system has already been discussed in great detail (Ćosić et al., 2011) as is the need for energy storage in cases where a lot of intermittent RES are being used (Krajačić et al., 2010). The utilization of reverse osmosis (RO) desalination coupled with brine operated pump storage hydroelectric power plants (BOPS) can provide a flexible electricity demand and energy storage. RO desalination is a commercially available and proven membrane desalination system used throughout the world (Hájek and Jegla, 2013). If designed properly RO desalination plants can provide water at a price of less than 0.8 $/m^3 of fresh water (Sassi and Mujtaba, 2011).
This paper presents a continuation of previous work where a similar analysis has alredy been conducted using the EnergyPLAN tool (Novosel et al., 2014). The goal of this work is to analyse and evaluate the impact desalination can have on the potential for the penetration of intermittent RES, namely wind and PV, using the energy planning tool H2RES. The critical excess of electricity production (CEEP) has been calculated and is presented here.

2. Methodology

In order to demonstrate the impact that desalination can have on the penetration of intermittent RES four scenarios have been created in the H2RES energy planning tool, one reference scenario without desalination and three desalination scenarios with different amounts of BOPS.

2.1 H2RES

H2RES is a flexible energy planning tool capable of balancing energy supply and demand on an hourly level. It is able to model single power plants, countries or whole regions individually or aggregated. The inputs needed to create a scenario in H2RES include the hourly electricity demand, hourly wind speeds and solar radiation, installed capacities and efficiencies of energy producers, intermittent limit, import/export capacities, economic parameters and so on. The outputs of the model are the energy produced from the individual sources, CEEP, cost of the system and so on.

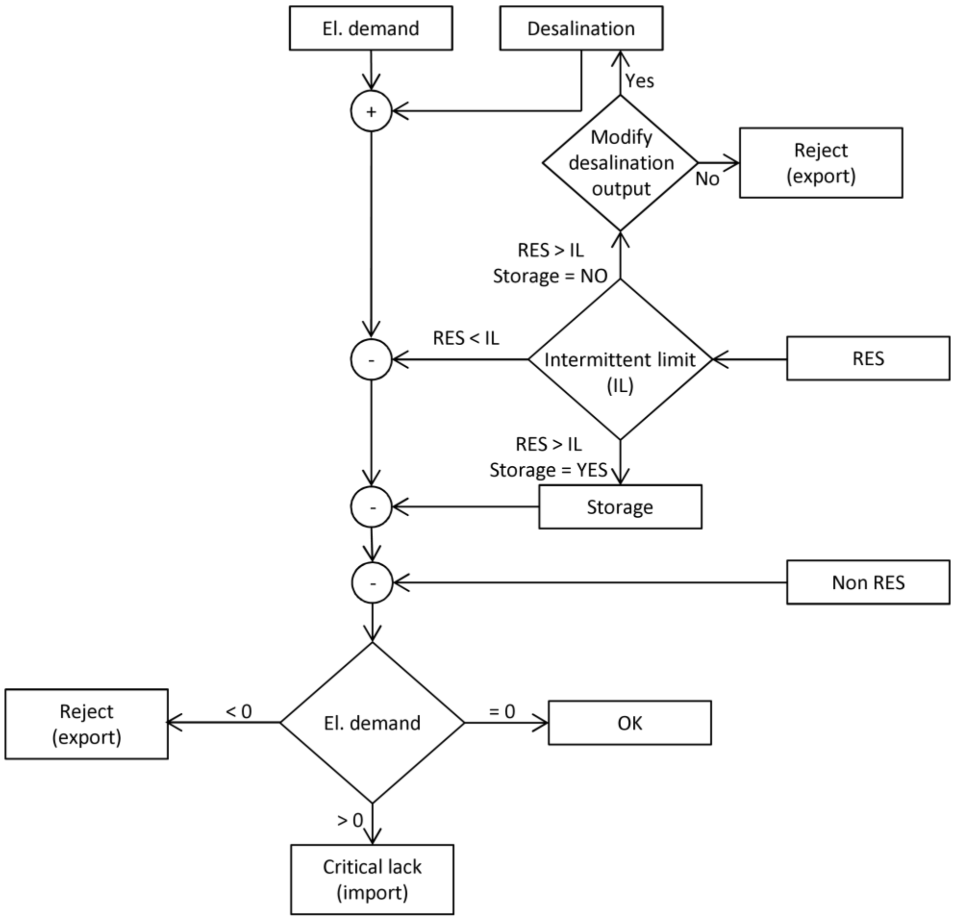

Figure 1. Basic structure of the H2RES energy planning tool

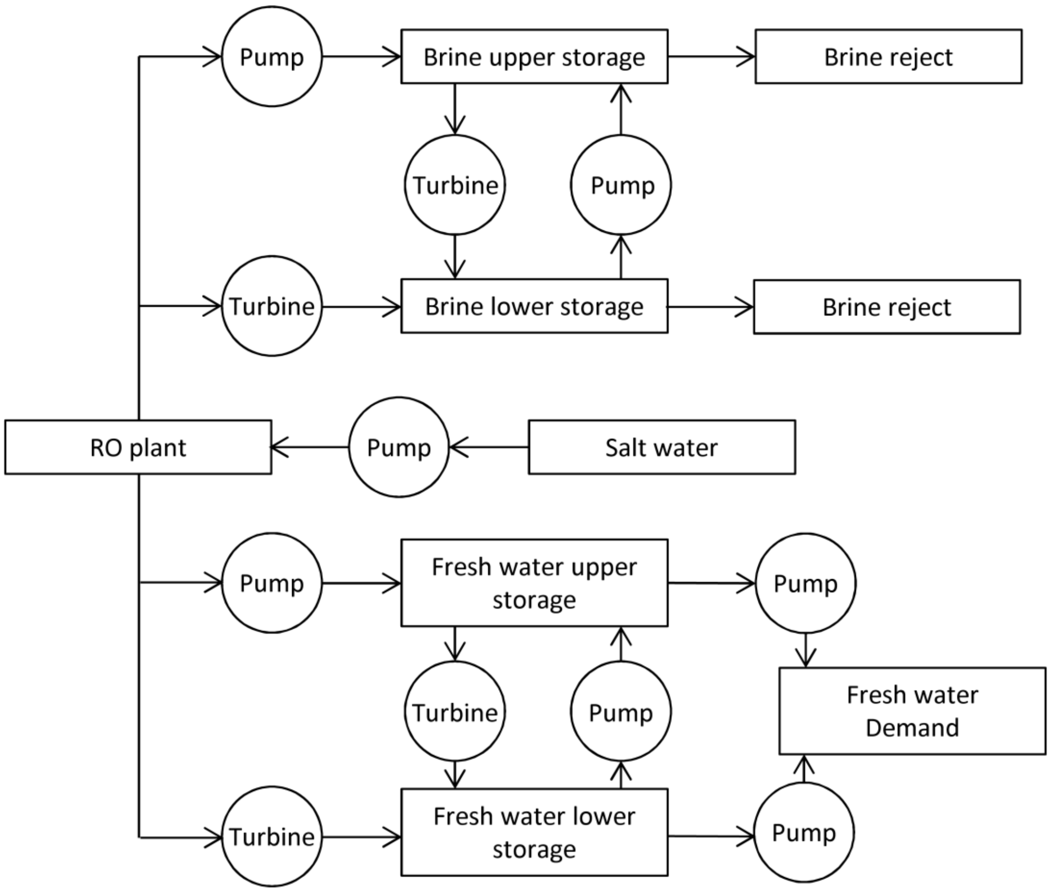

Figure 2. Desalination module in H2RES

H2RES uses a merit-order framework to rank energy sources by the criteria of least marginal cost of energy production. This puts RES on the highest level of priority since they have a negligible marginal cost when compared to conventional sources, like fossil-fuel plants. The merit-order framework is executed in an hour-by-hour sequence. The flowchart of the procedure is given in Figure 1. This presentation is given for a closed system meaning no import or export of energy and only for electrical energy and desalination. The desalination module presents an additional electricity demand added to the one entered into the model as one of the inputs. The calculated total electricity demand is then first satisfied by energy produced from RES. The energy system can only accept electricity produced from RES equal or lower to the set intermittent limit which represents an artificial penetration rate of intermittent RES. This limit is the primary generator of CEEP since all electricity produced from intermittent RES greater than the limit has to be stored, exported or, in the case when the first two options aren't available, rejected. This figure presents the need to have energy sources capable of providing grid regulation like hydro and thermal plants whose energy output can be regulated freely within their operational range. The system first tries to store excess electricity, if that is not possible it tries to modify the desalination output and finally, if that is not enough the excess is either exported or rejected. The rest of the energy demand is than satisfied first from energy storage and finally from non-renewable sources. Excess of electricity can appear here as well since large thermal power plants have a minimum capacity at which they operate and this can cause problems at higher penetrations of intermittent RES.

Figure 2 presents the flowchart for the desalination module in H2RES. It was designed to provide as much flexibility to the user as possible allowing the implementation of pump storage both on the brine and the fresh water side as well as allowing both water storages to work with either one or two storage lakes, upper and/or lower and allowing the lakes to be modelled as infinite or limited in capacity.

H2RES is a proven tool used in the past to model island energy systems (Krajacčić et al., 2009), 100 % renewable energy systems (Krajačić et al., 2011) and the possibilities of a high penetration of RES (Segurado et al., 2011) (Fowler et al., 2009) amongst others.

2.2 Case study: Jordan

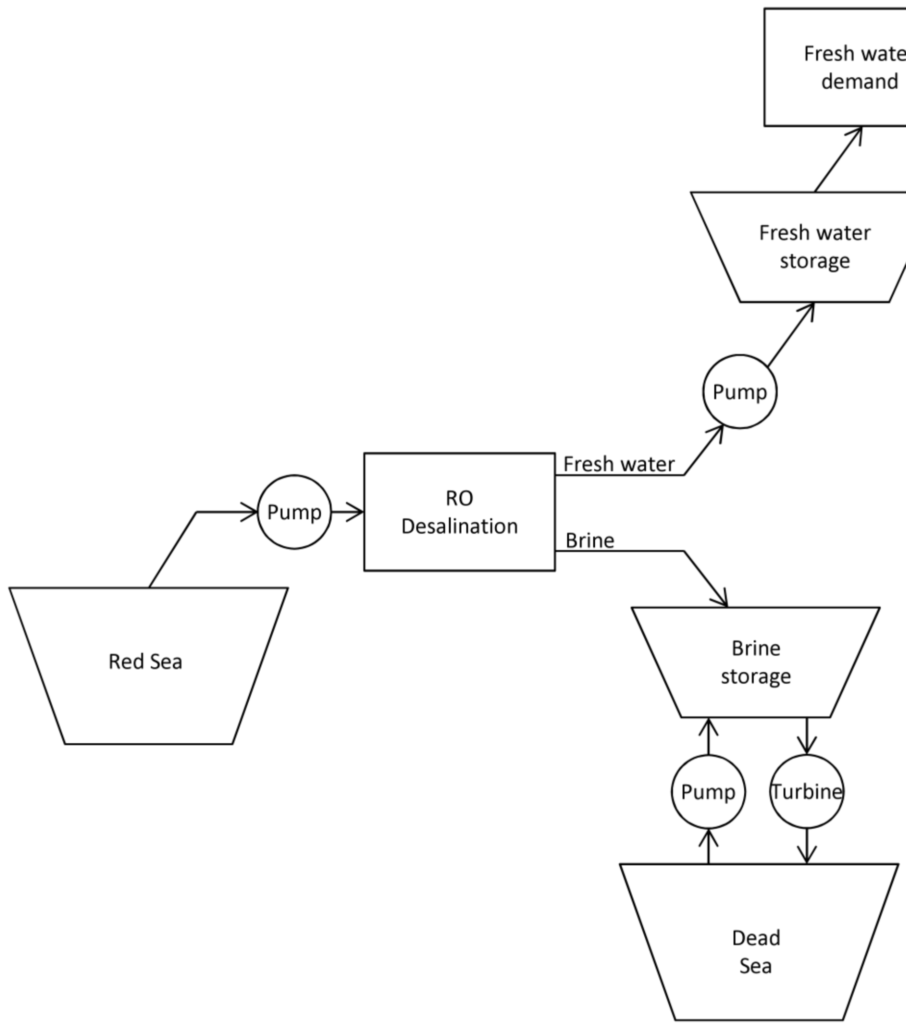

Figure 3. Desalination system

The Jordanian hourly energy demand has been obtained from the Jordanian National Electric Power company (NEPCO, 2013). The installed capacities of the energy producers have been taken from the NEPCOs annual report for the year 2010 (NEPCO, 2010). The intermittent limit has been set to 70% of the total electricity demand for all scenarios. The energy balances for large thermal power plants as well as other energy statistics have all been taken from the International Energy Agencies web site (IEA, 2013). The meteorological data for Jordan has been obtained from meteonorm (meteonorm, 2013).

The desalination system has been modelled according to the one proposed in the work of Michael Beyth (Beyth, 2007) but was adapted to allow for more flexibility and the utilization of BOPS. The general principle of the proposed installation is presented in Figure 3. The water can be pumped to an elevation of approximately 1,000 m above sea level where it can be desalinated. The Fresh water can then be pumped into a fresh water storage system and later on to the consumers while the brine could be stored in a brine storage lake and used in a BOPS system.

3. Results

Figure 4 and Figure 5 present the results of the preformed analysis for 4 scenarios, a reference scenario, a scenario with a desalination unit and two scenarios with a desalination unit and a BOPS system once with an installed power of 500 MW and once for 1,000 MW both with a storage capacity of 24 hours. This means a scenario with 500 MW of pumps and 500 MW of turbines and storage of 12 GWh and a scenario with 1,000 MW of pumps and 1,000 MW of turbines and a storage of 24 GWh. Figure 4 demonstrates the impact desalination and BOPS can have on wind power penetration. In the case of 50 % penetration, meaning that the electricity production from wind power equals 50 % of the total annual electricity demand, a reference scenario has CEEP equalling 21.85 % of the total annual electricity demand while a system with a desalination unit and a 1,000 MW BOPS has CEEP equalling 7.51 %.

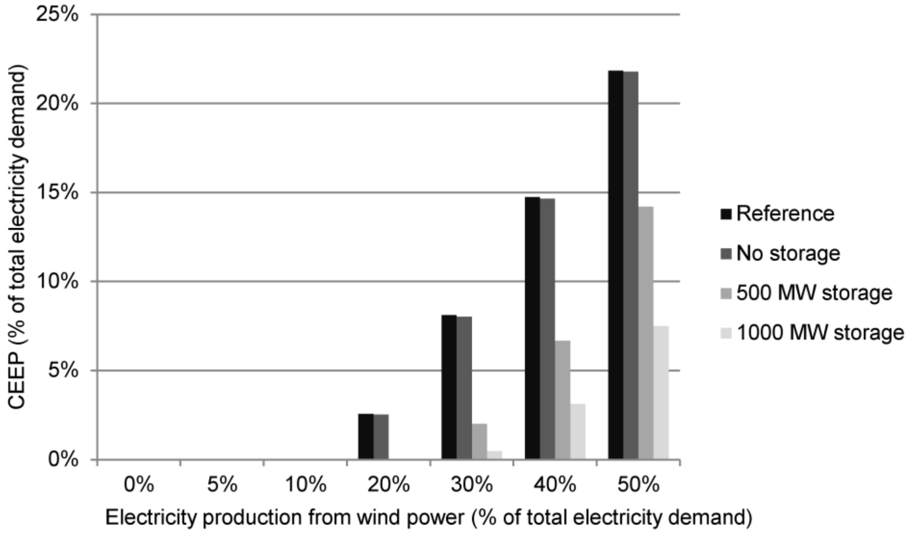

Figure 4 CEEP in relation to electricity production from wind power

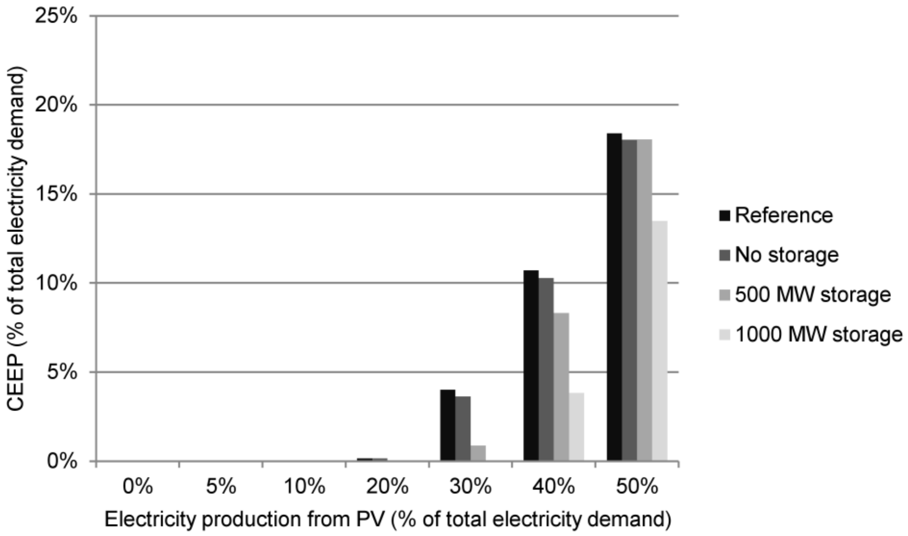

Figure 5 CEEP in relation to electricity production from PV

Figure 5 presents the same analysis but for PV penetration. In the case of 50 % the reference scenario has CEEP equalling 18.40 % of the total annual electricity demand while a system with a desalination unit and a 1,000 MW BOPS has CEEP equalling 13.48 %.

4. Conclusion

The results of the analysis of the presented scenarios created in the H2RES modelling tool have demonstrated that the utilization of a desalination system in combination with a BOPS system can have a significantly positive effect on the potential for the penetration of intermittent RES in an energy system.

CEEP is significantly reduced from its initial value in the reference scenario both for high penetrations of wind power and PV. This is especially obvious in the case of high wind penetrations and a 1,000 MW BOPS system where CEEP has been reduce from the initial value of 21.85 % in the reference scenario to 7.51 %. The lower amounts of CEEP for a system with no storage and high penetrations of PV in comparison to wind can be attributed to the distribution of electricity production that follows demand more closely in that case. Such a distribution is less beneficial when electricity storage is introduced to the system. The higher peeks around midday cannot be easily stored and the more evenly spread distribution of electricity production from wind is shown to be more beneficial. This is evident by the lower amounts of CEEP in the case of high penetrations of wind power in a combination with energy storage than for PV.
The utilization of such a system can have a substantially positive impact on an energy system as a whole and in the case of Jordan, and other arid countries, it could provide a significant amount of fresh water, reduce CO_2 emissions and increase the security of energy supply.

5. Acknowledgement

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